Tunable fiber confocal sensor with LED

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Abstract

A novel concept of confocal sensor based on focal lens is proposed to measure the displacement. The light source is a stabilized fiber coupled LED. A 1x2 graded-index multimode fiber optic coupler is used in this sensor. One port is a LED input port via SMA connector, another port is a LED output port connected to a reflective collimator and the other port is a reflective sensor port connected to a photo detector. The focusing sensor head is the cascade of a focal lens and a 20X objective lens. In this confocal displacement sensor, LED passes through a focal lens and an objective lens so that the LED beam focuses at a fixed focal point. A test target is placed after the objective lens. The displacement between the sensor head and a target can be measured quickly by detecting the reflective power according to the confocal principle. The long-term stability of LED is under 0.5%. The effective back focal length is varied from 5.67mm to 6.57mm by 0-290mA current driving so that the measuring range is about 0.9mm. The FWHM resolution of displacement is about 50μm. This sensor has the features of low cost, high stability, high precision and compact.

Keywords: LED, fiber, confocal sensor, tunable, displacement

1. INTRODUCTION

Several researches about confocal sensors applying to displacement or profile measurement were published. Confocal sensor systems with fiber optics were constructed in earlier papers [1]. The sensors are compact, small and low cost in construction because of the application of fiber optic. Another research used a diffractive optical element to apply multi-wavelength laser to confocal laser displacement sensor [2]. The multi-wavelength laser beams enhance the measuring range of the displacement sensor. But, they are still slow speed in displacement sensing. As a result, the applications of tunable lens in displacement sensors were published [3-4]. Because of the use of tunable lens, sensing speed of displacement sensors can be improved obviously. Therefore, the sensing speed of displacement sensors with tunable lens is fast enough to be applied in 3D profile scanning.

In this paper, we proposed a tunable fiber confocal sensor with LED that is based on confocal principle with some modifications. Different objective lenses magnification factor could be switched for different scanning ranges. It has been proved in this study that this displacement sensor could be practically used in high precision displacement sensing. The focal length of the tunable lens can be changed easily by varying the driving current. On the other hand, this sensor could be applied to the manufacture process to achieve real-time monitoring of the manufacturing precision because of the fast, efficient and high-precision characteristics of the displacement sensor. This sensor has the features of low cost, high stability, high precision and compact.

2. SYSTEM SETUP

The photograph of this tunable fiber confocal sensor with LED is shown in Fig.1. It is a compact hand-held system that can measure distance quickly and conveniently. In this tunable fiber confocal sensor with LED, a LED beam passes through a multi-mode fiber coupler, collimator, tunable lens and objective lens and then focused in a fixed focal length. A target is placed after the obj. lens to be scanned. The CCD in the 3D schematic diagram will be putted in this sensor to achieve higher accuracy. In order to complete an efficient and economical displacement sensor, the use of a tunable lens and LED light source plays an important part that differ this sensor system from a common laser confocal displacement sensor. The profile of the tunable lens can be quickly and easily varied by changing the driving current because the tunable lens is made of liquid and electric conductors around the liquid. Displacement of targets could be measured more quickly without any mechanical moving device with this tunable lens. This lens was placed before objective lens in this system so that the system equivalent focal length can be quickly changed. The driving current could be controlled by computers with our LabVIEW program. And the focal power of the varifocal liquid lens could be changed from 8dpt to

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22dpt, which is linear to the driving current. The setting time of the lens is less than 15ms. The LED light source makes this sensor cheaper and more convenient. The multimode 1×2 fiber coupler is used to lead the reflective beam from the target to a power meter to analyze the reflective beam from target. A collimator is connected to the fiber coupler to collimate the light from fiber coupler. 10×, 20×, 50× and 100× objective lenses are used in this system to improve the accuracy of the sensor system in each different measurement condition. In order to complete 3D scanning principle testing, the targets were placed in a 3D manual translation stages. When testing the properties of this tunable fiber confocal sensor with LED, the target on the stage was moved along z-axis. And it could be moved along x-y plane in a 3D measurement procedure. As a result, a 3D measurement system is completed with combining the displacement sensor and a 3D stage. For the purpose of quick demonstration, this stage is adjusted by manually now. In the future, an electrical driving stage or a 2D scanning Galvo scanner will be integrated to this system. This tunable fiber confocal sensor with LED measures the reflective power then analyze the curve of the reflective power versus displacement to determine the position of target when the LED beam pass through in sequence the fiber coupler, tunable lens and Obj. lens and then focus on the target. The beam reflects from the target due to partially reflectance and is collected into fiber coupler connected to power meter by the tunable lens and obj. lens and in the reverse configuration direction. The USB dongle is connected to a personal computer with LabVIEW control program to supply different current to make the tunable lens vary the focal length and focus the LED beam in this sensor system until the reflective power archive to the relative maximum. And the corresponding driving current of the relative maximum reflective power was recorded and analyzed. According to the above, the relationship between focal length (displacement), driving current, and reflective power could be analyzed and defined by above steps. A 3D scanning system could be completed by moving the target along x-y plane and analyzing the displacement on z-axis.

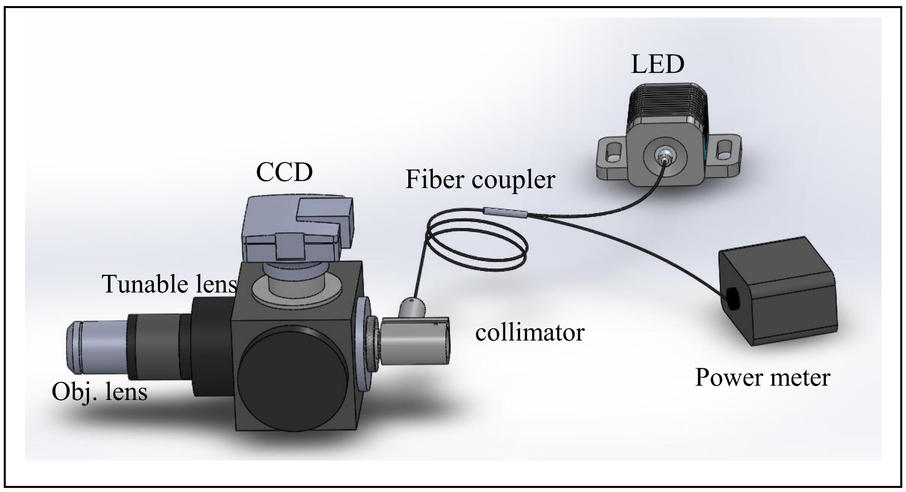

Fig. 1 Schematic diagram of the tunable fiber confocal sensor with LED.

3. EXPERIMENTAL RESULTS AND DISCUSSION

In order to avoid mechanical moving progress and achieve an efficient displacement sensing, the tunable lens plays an important part in this tunable fiber confocal sensor with LED. Focal length of the sensor head can be quickly varied by changing the driving current to this tunable lens. The reflective power and the driving current could be easily detect and record by computer. Analysis of the displacement of the target was done by our LabVIEW program with PC interface. In order to analyze the displacement of the target, the relationship between the driving current and the displacement of this system is an important information. Therefore, several experiments were done to measure the correlation equation between the displacement and the driving current. Fig.2 shows the result correlation curves about the driving current and the corresponding focal point of different objective lens. For the reason to suit different sensing conditions, different obj. lens like 10×/20×/50×/100× were placed to identify the different sensing range. To compare the tendency of each curves more clearly, all the distance of focal length are represented in relative distance. To complete the experiment about defining the relationship, different current from 0 to 290 mA was supplied to the tunable lens and LED beam passed though the tunable lens in time sequence. A test mirror was placed on the 3D stage and was used as a sensing target. Then each displacement corresponding to each maximum power in every fixed driving current was recorded by detecting reflective power curves from the target in every fixed driving current. As shown in Fig.2, curves with different obj. lens are smooth and have the same predictable trends. Sensing ranges of the system are about 4.6mm, 1mm, 0.15mm and 0.03mm with equipping 10×, 20×, 50× and 100× obj. lenses, respectively. These result curves indicate the highest accuracy of the fiber confocal sensor with equipping 100× obj. lens because of the smallest sensing range with the same interval of driving current, accuracy of the sensor with 100× obj. lens is expected to several nanometer But sensing range with 10× Obj. lens is the largest. And the curves with 20× and 50× obj. lens are more linearly than the other two.

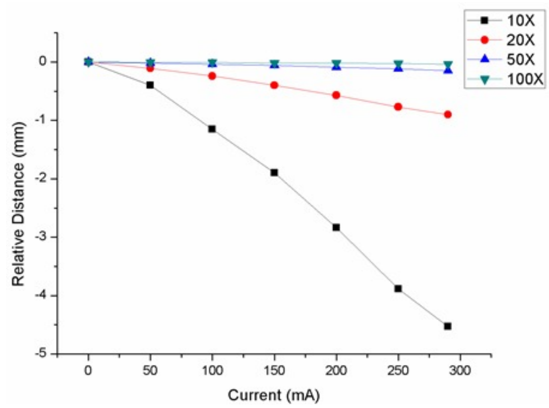

Fig. 2 Relationship between the displacement and driving current of different obj. lens.

The different objective lens are used to improve the accuracy and precision of this tunable fiber confocal sensor with LED. 10×, 20×, 50× and 100× obj. lens were used to be switched in different measurement requirement in this study. To identify the different sensing purpose with the four different objective lens. The different accuracy of the displacement sensor with equipping the four different objective lens have been measured and compared. The experiment result is showed in Fig.3. Four different reflective power with these obj. lens were detected in different fixed distance between the sensor head and a mirror as target. To compare the curves more obviously, all the reflective power were normalized. The resolutions of the sensor with the four obj. lens were defined in full width at half maximum (FWHM). It is obviously that the resolution in displacement of the sensor with 100× and 50× obj. lens is several time higher than the other two by comparing the width of FWHM in distance. As a result, it is better to use 100× or 50× obj. lens to achieve higher resolution in precision measurement. However, it is suggested to choose 20× or 10× obj. lens when scanning a large sample because of the larger sensing range with the two objective lens.

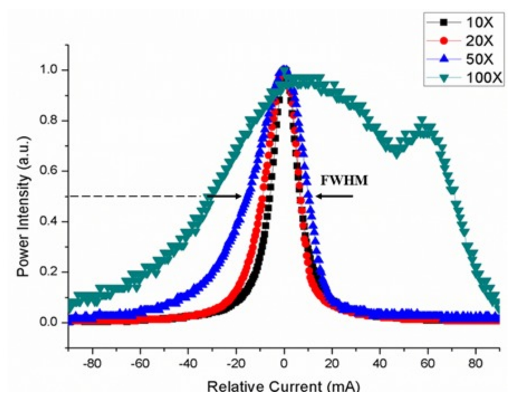

Fig. 3 Diagram of detected reflective power to the driving current with different Obj. lens.

To verify the performance of the tunable fiber confocal sensor with LED in a real scanning application, a sample which is a step-shape target made of aluminum set on the 3D stages was scanned. The steps of the sample are about 0.08mm high. The picture and scanned area of the sample is indicated in Fig. 4(a). To compare the error in this experiment, the sample was scanned by a confocal microscope to measure the real height of each step. Four points that correspond to the four steps scanned by the confocal microscope were chosen to be scanned. For the reason to adapt the height range of these steps, 20× objective lens was used. Different power-current curves of the points sketched in Fig. 4(b) were scanned by moving the sample along x-axis in the manual 3D stage. The result error compared to the height measured by confocal microscope is less than 0.013mm (13μm). These errors could be caused by surface roughness, type of fiber coupler, stability of this system, temperature effect of the tunable lens.

(a) (b)

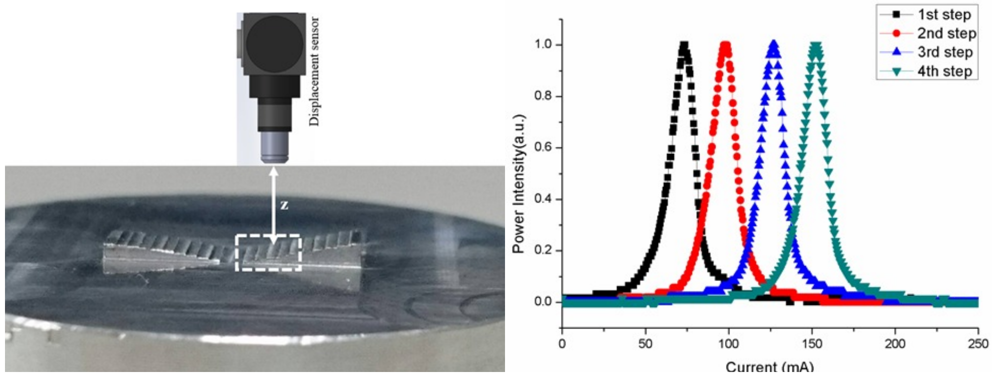

Fig. 4 Photograph and Schematic diagram of the motherboard as a real sensing target. (a) The photograph of the step-shape sample and schematic of the sensor. (b) Measured power-current curves of each point.

4. CONCLUSION

A tunable fiber confocal sensor with LED is successfully demonstrated. It has been proved in this study that this displacement sensor could be practically used in high precision displacement sensing. On the other hand, this sensor could be applied to the manufacture process to achieve real-time monitoring of the manufacturing precision because of the fast, efficient and high-precision characteristics of the displacement sensor. Furthermore, we are planning to mount all the equipment of this sensor system into a modular instrument with practical application. In the future work, the high-speed photo-detector with DAQ card will be used instead for improving measurement time.

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REFERENCES

[1] N. Koukourakis, M. Finkeldey, M. Stürmer, C. Leithold, N. C. Gerhardt, M. R. Hofmann, U. Wallrabe, J. W. Czarske, and A. Fischer, "Axial scanning in confocal microscopy employing adaptive lenses (CAL)", Opt Express. ,22(5), pp. 6025-39, 2014.

[2] Phuong-Ha Cu-Nguyen, A. Grewe, M. Hillenbrand, S. Sinzinger, A. Seifert, and H. Zappe, "Tunable hyperchromatic lens system for confocal hyperspectral sensing", Opt Express. , 21(23), pp. 27611-21, 2013.

[3] H. Ahmad, M. Yasin, K. Thambiratnam, S.W. Harun, "Fiber optic displacement sensor for micro-thickness measurement", Sensor Review, Vol. 32 Iss: 3, pp. 230 - 235, 2012.

[4] K. Noda, N. Binh-Khiem, Y. Takei, T. Takahata, K. Matsumoto, and I. Shimoyama, "Multi-axial confocal distance sensor using varifocal liquid lens", The 17th International Conference on Solid-State Sensors, Actuators and Microsystems, pp.1499 - 1502, 2013.